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Modelling approaches and experimental analysis of measurement uncertainty in radiated susceptibility tests

Abstract

The necessity to establish adequate uncertainty budgets of radiated susceptibility tests is well known in EMC testing. A model describes the structure of susceptibility tests and their influence factors. Based on recent results a preliminary uncertainty budget is provided which consists of contributions for calibration, test and the effect of the device under test (DUT). To investigate the influence of the DUT a special test device for radiated susceptibility tests has been developed. Experiments using this test device were carried out in a GTEM cell and an anechoic chamber.

1. Introduction

According to the standard ISO/IEC 17025 EMC laboratories have to apply a procedure to determine the measurement uncertainty in their tests. For radiated emission measurements the value of estimated measurement uncertainty can be related directly to the emission of the device under test. As shown in fig. 1 the measurement value y is influenced by several contributions $x_{1..N}$ which can be combined and modelled in a function. The treatment of measurement uncertainties in emission measurements is defined in CISPR 16-4-2.

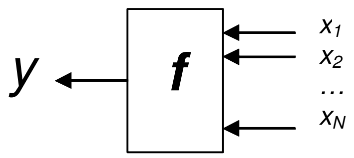


Fig.1 Functional relation f between influence variables $x_{1..N}$ and measurement value y

The measurement uncertainty of radiated susceptibility tests is a recent focus of research in EMC testing. In contrast to emission measurements, where commonly accepted methods of uncertainty analysis exist, radiated susceptibility tests usually give only a simple pass or fail result. Therefore a special test device for radiated susceptibility tests has been developed in order to obtain a measurement value *y*. This test result depends on the test field strength and can be used as the basis for the investigation of the measurement uncertainty. Thus the contributions of the DUT to the uncertainty can be considered in the uncertainty budget. The model structure for susceptibility tests is shown in fig. 2.

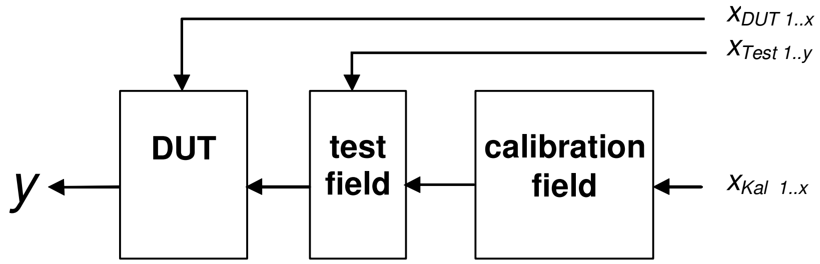


Fig. 2 Model structure for susceptibility tests

To evaluate the deviations of the overall system the following functional correlation can be assumed as $U_{MR} = f\,(E_{nom}, P_{cal}, E_{cal}, P_{test}, k_1, k_2, k_3, \ldots, k_N)$ where U_{MR} is a function of the calibration quantities P_{cal} and E_{cal} as well as the test quantity P_{test} and several influence parameters k_N.

- E_{nom} is the nominal field strength, target field surrounding the DUT
- P_{cal} is the power during calibration process
- E_{cal} is the field strength during calibration process
- P_{test} is the power during test process
- U_{MR} is the output voltage of the measurement receiver (DUT) during test process

2. Structure of influencing factors in an EMC susceptibility test system

Fig. 3 shows the entry points of influence factors within the calibration and test procedure regarding radiated susceptibility tests. Some variables are only concerning the generation of the reference file during calibration of the test environment. The dominant contribution results from the factor $k_{e.field}$ regarding the uniform area for the 6-dB-criterion which may cause a 100 % deviation in the uncertainty budget.

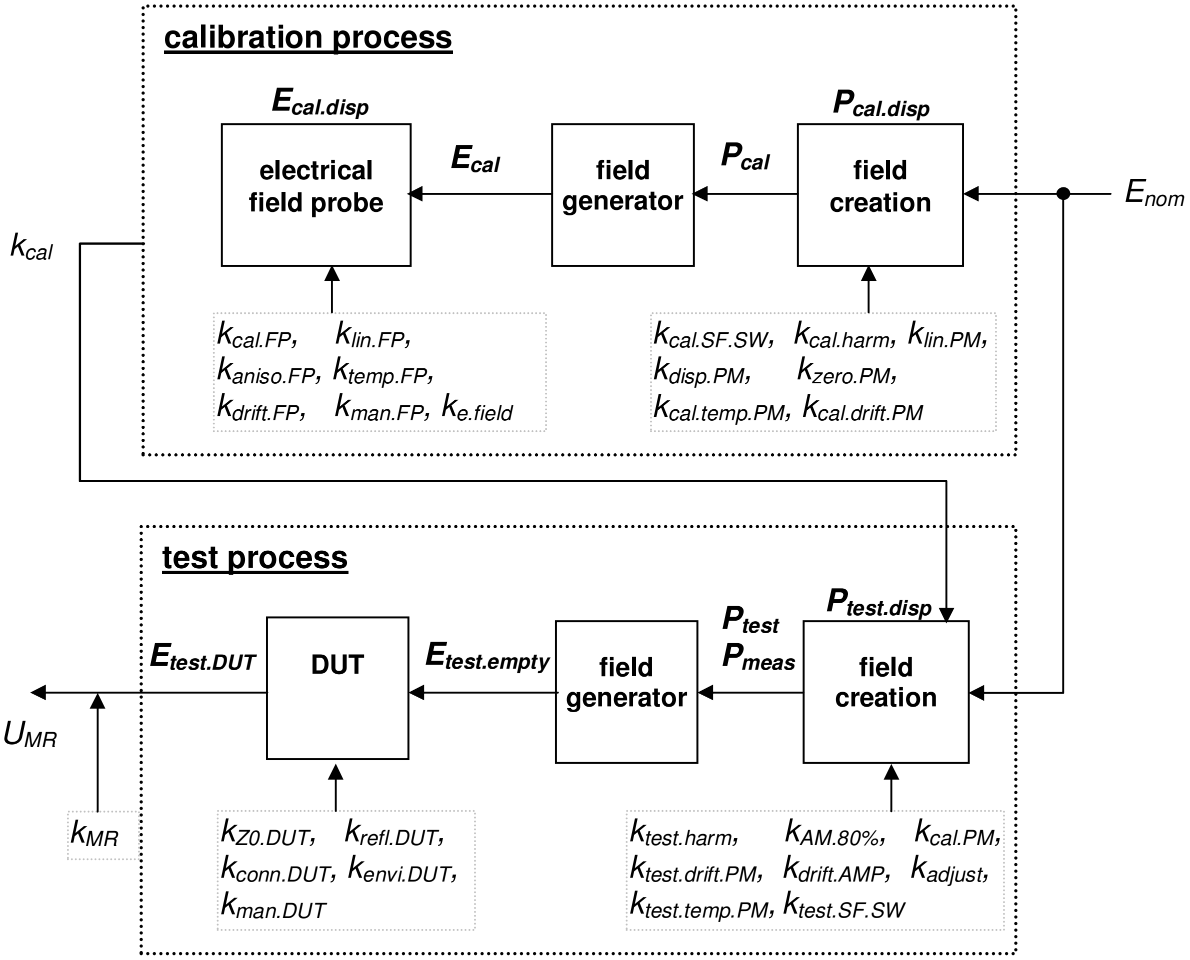


Fig. 3 Structure of an EMC susceptibility test system

The structure in fig. 3 decribes in detail the elements of a susceptibility test system and their influence factors concerning calibration process in the upper part and test process in the lower part.

3. Uncertainty budget for a GTEM cell

The uncertainty contributions for susceptibility tests in a GTEM cell are listed in table 1. The influence quantities can be obtained from data sheets, manufacturer specifications, from calibration certificates or can be derived by practical experience or experiments. An expanded uncertainty of 16 % was calculated for the GTEM cell, which was investigated at PTB in Berlin.

The correlation between the influence factors in table 1 shown below are focus of further investigations.

Quantity	Explanation	Distribution	Source
E_{nom}	Nominal field strength at DUT	none	target value
	1. calibration procedure		
P_{cal}	Real RF power at directional coupler (for E_{cal})	none	interim value
$P_{cal.disp}$	Displayed RF power at directional coupler	none	entry value
E_{cal}	Real field strength value of GTEM cell with electrical field probe	none	interim value
$E_{cal.disp}$	Displayed field strength value of electrical field probe	none	entry value
k_{cal}	Transfer factor between input power and created field strength in GTEM cell during calibration procedure, writing reference file	none	interim value
$k_{cal.SF.SW}$	Susceptibility software is controlling input power only within def. limits	rectangular	SW settings
$k_{cal.harm}$	Influence of amplifier harmonics	open	open
$k_{disp.PM}$	Display accuracy of power meter	rectangular	specification
$k_{zero.PM}$	Zero drift of power meter	rectangular	specification
$k_{lin.PM}$	Linearity drift of power meter	rectangular	open
$k_{cal.temp.PM}$	Temperature drift of power meter	rectangular	open
$k_{cal.drift.PM}$	Long time drift between 2 calibrations of power meter during calibration	rectangular	open
$k_{cal.FP}$	Calibration factor of electrical field probe,(<1 GHz: 12 %, >1 GHz: 7 %)	normal	cal. paper
$k_{lin.FP}$	Linearity of electrical field probe	rectangular	specification
$k_{aniso.FP}$	Anisotropicity of electrical field probe	rectangular	specification
$k_{temp.FP}$	Temperature dependence of electrical field probe	none	compensated
$k_{drift.FP}$	Drift of electrical field probe between 2 calibrations	rectangular	open
$k_{man.FP}$	Manual positioning of electrical field probe (uniform area)	normal	open
	2. test procedure (main)		
P_{meas}	Power at directional coupler during setting of nominal field strength	none	interim value
P_{test}	Power at directional coupler during setting of test field strength (can be different from nominal field strength)	none	interim value
$P_{test.disp}$	Displayed RF power at power meter	none	entry value
P_{calc}	Calculated RF power from nominal field strength & transfer factor	none	interim value
$k_{test.harm}$	Influence of amplifier harmonics	open	open
$k_{AM.80\%}$	Additional harmonics occurring if signal modulation is switched on (problem of amplifier limitation)	open	open
$k_{cal.PM}$	Calibration coefficient of power meter if 2 different power meters are used for calibration and test	normal	open
$k_{test.drift.PM}$	Long time drift between 2 calibrations of power meter during test	rectangular	2 cal. papers
$k_{drift.AMP}$	Drift of amplifier after set of field strength (i.e. dwell time)	rectangular	open
$k_{test.temp.PM}$	Temperature drift of power meter	rectangular	open
k_{adjust}	Deviation between calculated (deviating from reference value) und real measured power (linearity error of power meter)	rectangular	open
$k_{test.SF.SW}$	Software is controlling input power only within given limits	rectangular	SW settings
	2.1 empty field		
$E_{test.empty}$	Real value of field strength in GTEM cell at test position w/o DUT	none	interim value
	2.2 test field (impact of DUT)		
$E_{test.DUT}$	Real value of field strength in GTEM cell at test position with DUT	none	interim value
$k_{Zo.DUT}$	Influence of DUT on wave impedance	open	open
$k_{refl.DUT}$	Reflection properties of DUT	open	open
$k_{conn.DUT}$	Influence of connections to DUT	open	open
$k_{envi.DUT}$	Influence of environment on DUT as temperature, relative humidity	open	open
$k_{man.DUT}$	Manual positioning of DUT	open	open
k_{MR}	Converting field around DUT into voltage level of meas. receiver	open	open
U_{MR}	Measurement value of receiver	none	test value

	3. influence of uniform area		
$k_{e.field}$	Deviation caused by uniform area (0..6dB criterion), frequency dependent	rectangular	open

Tab. 1 Influence variables and uncertainty contributions

4. Functional relation of influence factors

The uncertainty of susceptibility tests can be described by the deviation U_{MR} of detected field strength at the measurement receiver.

The voltage level detected by the measurement receiver is linked to the nominal field strength and frequency dependent influence factors k.

$$U_{MR} = f(E_{nom}, k_1, k_2, k_3, ..., k_N)$$

This voltage level U_{MR} corresponds to the field strength surrounding the test device during the test procedure. This can be written as

$$U_{MR} = k_{MR} \cdot E_{test.DUT} .$$

The field strength at the test device itself depends on the field strength of the empty field and several DUT specific variables caused by the measurement receiver

$$E_{test.DUT} = k_{man.DUT} \cdot k_{conn.DUT} \cdot k_{Z0.DUT} \cdot k_{envi.DUT} \cdot k_{refl.DUT} \cdot E_{test.empty} .$$

The empty field strength is impacted by the reference file created during calibration procedure k_{cal} and the power P_{test} used for test procedure

$$E_{test.empty} = k_{cal} \cdot \sqrt{P_{test}} .$$

If the test field strength differs from that used in calibration procedure the factor k_{adjust} is necessary

$$P_{test} = k_{adjust} \cdot P_{meas} .$$

The relation between the power P_{meas} for setting nominal field strength and the displayed power value $P_{test.disp}$ during test procedure is given by correction factors concerning power meter and amplifier

$$P_{meas} = P_{test.disp} \cdot k_{AM.80\%} \cdot k_{drift.AMP} \cdot k_{test.harm} \cdot k_{cal.PM} \cdot k_{test.driftPM} \cdot k_{test.tempPM} \cdot k_{test.SF.SW} \cdot k_{test.PM} .$$

The relation between power and field strength is represented by the factor k_{cal} and written into the reference file that is used in test procedure during calibration procedure.

$$k_{cal} = \frac{E_{cal}}{\sqrt{P_{cal}}} .$$

For proper calculating the real value of E_{cal} and P_{cal} it is necessary to determine the display values for $E_{cal\ disp}$ and $P_{cal\ disp}$ including their influence factors regarding power meter and electrical field probe

$$E_{cal} = E_{cal.disp} \cdot k_{cal.FP} \cdot k_{lin.FP} \cdot k_{aniso.FP} \cdot k_{temp.FP} \cdot k_{drift.FP} \cdot k_{man.FP}$$

$$P_{cal} = P_{cal.disp} \cdot k_{cal.SF.SW} \cdot k_{cal.harm} \cdot k_{disp.PM} \cdot k_{zero.PM} \cdot k_{lin.PM} \cdot k_{cal.temp.PM} \cdot k_{cal.drift.PM} .$$

Finally the detailed overall formula approach can be given as

$$U_{MR} = k_{MR} \cdot k_{man.DUT} \cdot k_{conn.DUT} \cdot k_{Z0.DUT} \cdot k_{envi.DUT} \cdot k_{refl.DUT}$$

$$\cdot \frac{E_{cal.disp} \cdot k_{cal.FP} \cdot k_{lin.FP} \cdot k_{aniso.FP} \cdot k_{temp.FP} \cdot k_{drift.FP} \cdot k_{man.FP}}{\sqrt{P_{cal.disp} \cdot k_{cal.SF.SW} \cdot k_{cal.harm} \cdot k_{disp.PM} \cdot k_{zero.PM} \cdot k_{lin.PM} \cdot k_{cal.temp.PM} \cdot k_{cal.drift.PM}}}$$

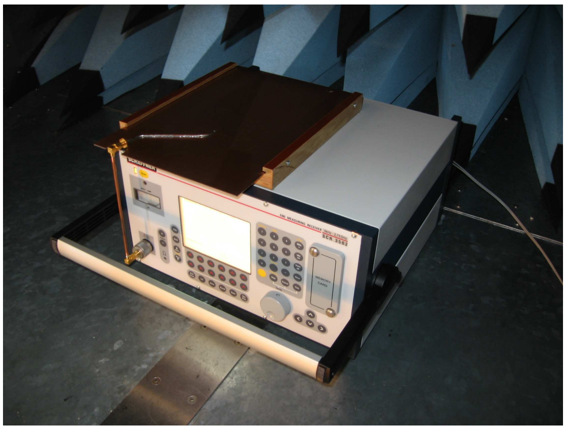
$$\cdot \sqrt{k_{adjust} \cdot P_{test.disp} \cdot k_{AM.80\%} \cdot k_{drift.AMP} \cdot k_{test.harm} \cdot k_{cal.PM} \cdot k_{test.drift.PM} \cdot k_{test.temp.PM} \cdot k_{test.SF.SW} \cdot k_{test.PM}}$$

To get a simple view similar factors are combined:

$$U_{MR} = k_{MR} \cdot k_{DUT} \cdot \frac{E_{cal.disp} \cdot k_{FP}}{\sqrt{P_{cal.disp} \cdot k_{cal.SW} \cdot k_{cal.harm} \cdot k_{cal.PM}}} \cdot \sqrt{k_{adjust} \cdot P_{test.disp} \cdot k_{test.harm} \cdot k_{test.PM} \cdot k_{test.SW}} \, .$$

5. Detecting field strength under “real” conditions in susceptibility tests

A special test device for experimental research was developed in cooperation of PTB Berlin and Schaffner Electrotest GmbH. The device shown in fig. 3 is based on a measurement receiver which is enhanced by a coupling structure for detecting electromagnetic fields. This device enables to link the evaluation of the radiated susceptibility tests to a measurable quantity. The receiver is powered by battery and provides stable and reproducible measurement results. Data can be transmitted via fiber optic cable to the control equipment.



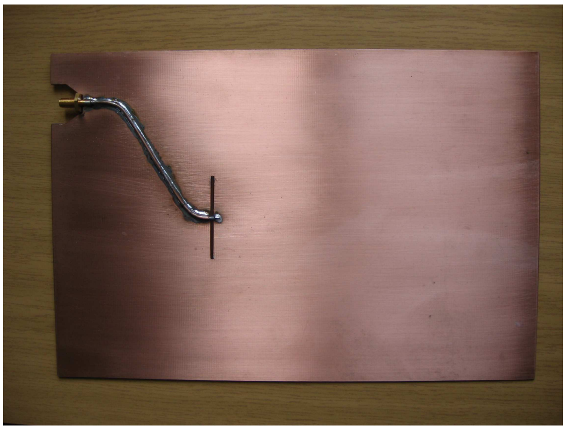


Fig. 4 Measurement receiver SCR 3502 with field coupling structure

The influencing variables on the measurement value U_{MR} of the receiver are concerning:

- the power values required for the creation of the nominated test field strength (i.e. the field strength which needs to be reached in the calibration process)
- the drift of the amplifier and the power meter during the test process
- the feedback of the DUT back to the test system depending on its size, form and reflective properties

6. Investigations in a GTEM cell and an anechoic chamber

Using the receiver as a test device a number of measurements were carried out in a GTEM cell and in an anechoic chamber (FAC) in order to allow the quantification of the impact of influencing variables on the uncertainty budget of radiated susceptibility tests as well as the comparison of different EMC test environments.

The diagram in fig. 5 shows how the result U_{MR} of the measurement receiver depends on the number of different orientations of the test device at test position. The results obtained from the maxima of 3 manipulator orientations around orthoaxis are quite similar to 8 orientations (4 times around x-axis & 4 times around y-axis) as defined in IEC 61000-4-20.

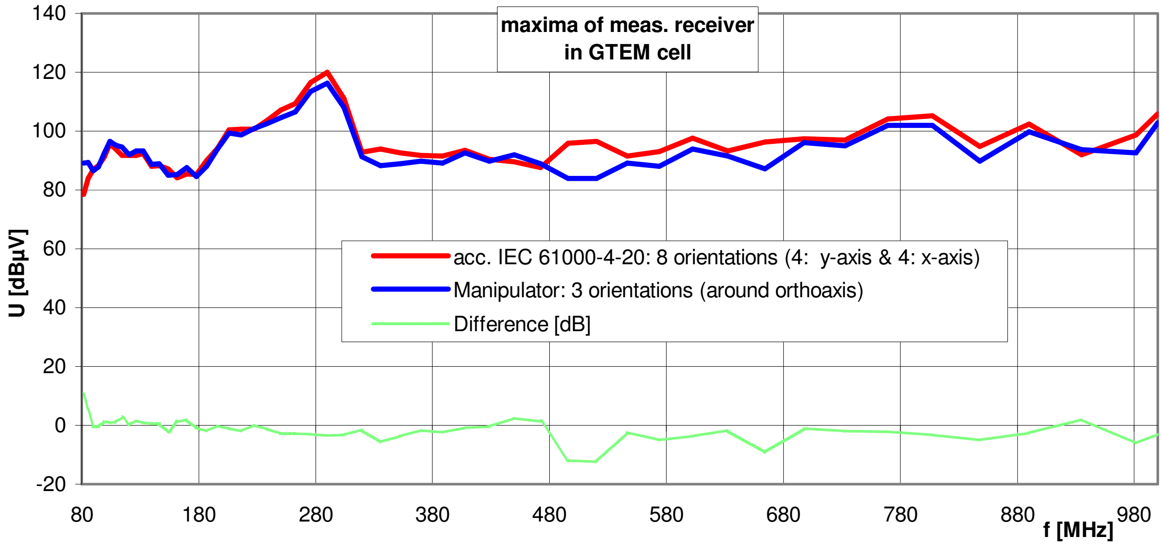


Fig. 5 Receiver values in GTEM cell comparing different DUT orientations

Fields generated in different field generators (e.g. GTEM cell, anechoic chamber, reverberation chamber) are influencing the DUT each in their own way and are therefore leading to varying measured values at the receiver. The diagram in fig. 6 compares two different coupling structures on measurement receiver as loop and slot antenna within a GTEM cell and a fully anechoic chamber. These structures are common electronical PCB patterns in test devices which have to be EMC tested.

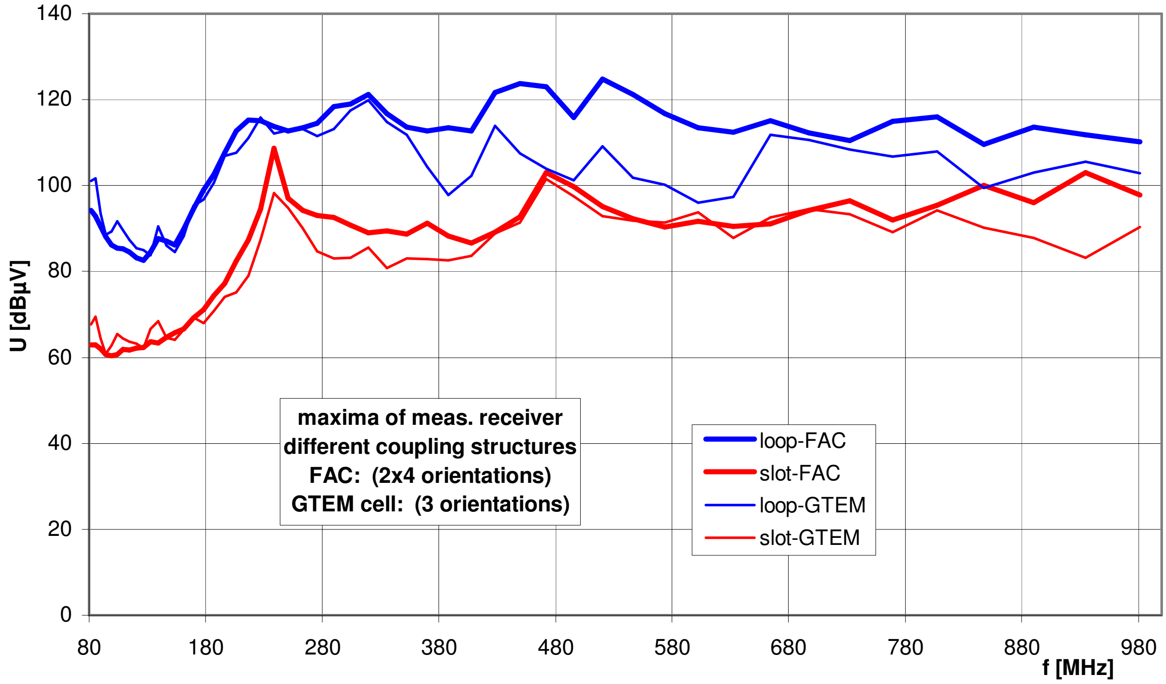


Fig. 6 Receiver values of GTEM cell and FAC comparing coupling structures

Additionally there will be impact of connecting cables, positioning of the test object and others. This behavior and other comparative tests in various EMC test environments as well as in reverberation chambers and in open area test sites are planned.

7. Conclusions

A first approach to establish an uncertainty budget for radiated susceptibility tests was presented. The uncertainty budget consists of contributions for calibration, test and the influence of the DUT. The effect of the DUT has been investigated experimentally using a specially developed test object. Based on this idea the further research will include finding the dominant influence parameters for calibration and test procedure as well as the effect of the test device on the test environment.

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